EuCAP 2014

Analysis of NURBS Dielectric Volumes by Using the Method of Moments

Electromagnetic Computing Group
Computing Sciences Department

University of Alcalá. 28871. Alcalá de Henares. Madrid, Spain

Javier Moreno, Iván González, Mª. Jesús Algar, Felipe Cátedra

Index

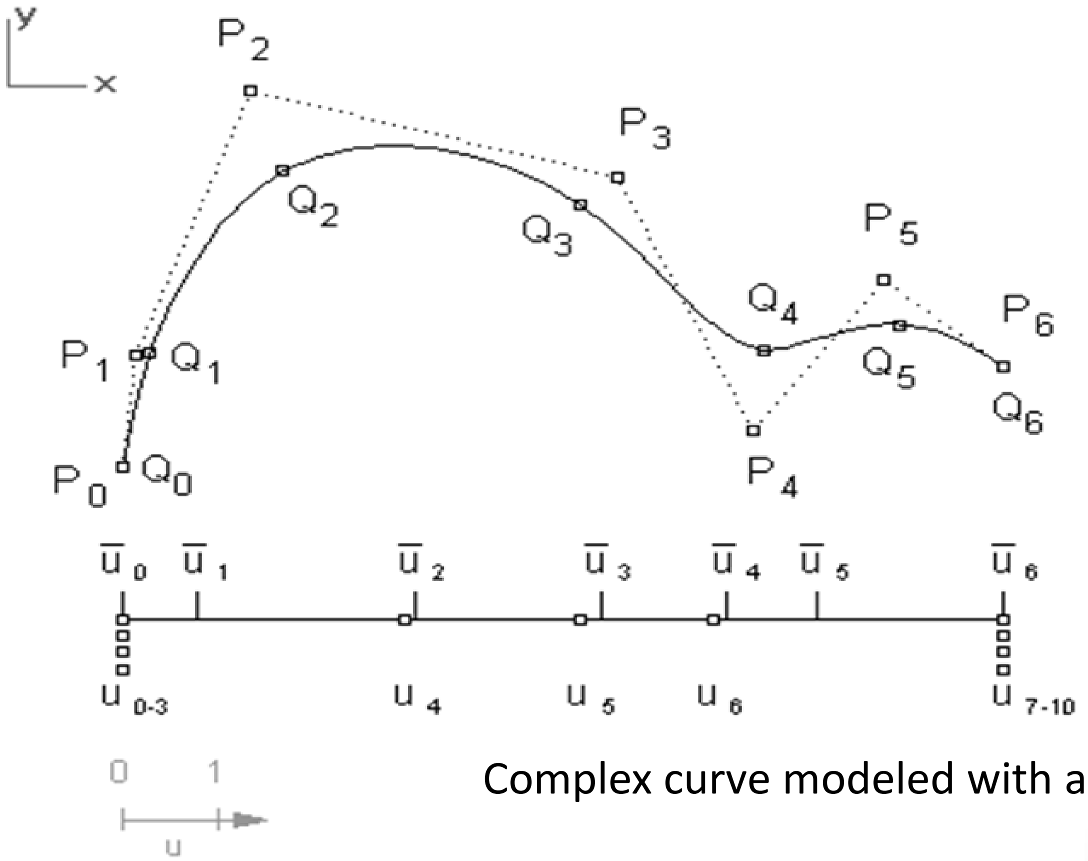
1. Introduction
2. Geometry Modelling
    1. NURBS Modelling
    2. Mesh generation
3. Method of moments on NURBS volumes: subdomains and CBFs approaches
4. Results
    1. Dielectric sphere
    2. Frequency Selective Surface
    3. Radome
    4. Lens antenna
    5. Radome with FSS
5. Conclusions

1. Introduction

- Electromagnetic analysis of dielectric complex objects and conductors
- Method of Moments
  - Superficial unknowns
    - Electric Field Integral Equation (EFIE)
    - Combined Field Integral Equation (CFIE)
  - Dielectric volumetric unknowns
    - Volumetric Electrical Field Integral Equation (VEFIE)
  - Multilevel Fast Multipole Algorithm (MLFMA)

2. Geometry Modelling

- NURBS entities provide more accurate models than flat faceting methods.


y
x
P_2
P_3
Q_2
Q_3
P_5
Q_4
P_6
P_1
Q_1
Q_5
Q_6
P_4
P_0
Q_0
$\bar{u}_0$
$\bar{u}_1$
$\bar{u}_2$
$\bar{u}_3$
$\bar{u}_4$
$\bar{u}_5$
$\bar{u}_6$
u_{0-3}
u_4
u_5
u_6
u_{7-10}
0
1
u

Complex curve modeled with a NURBS line

2. Geometry Modelling

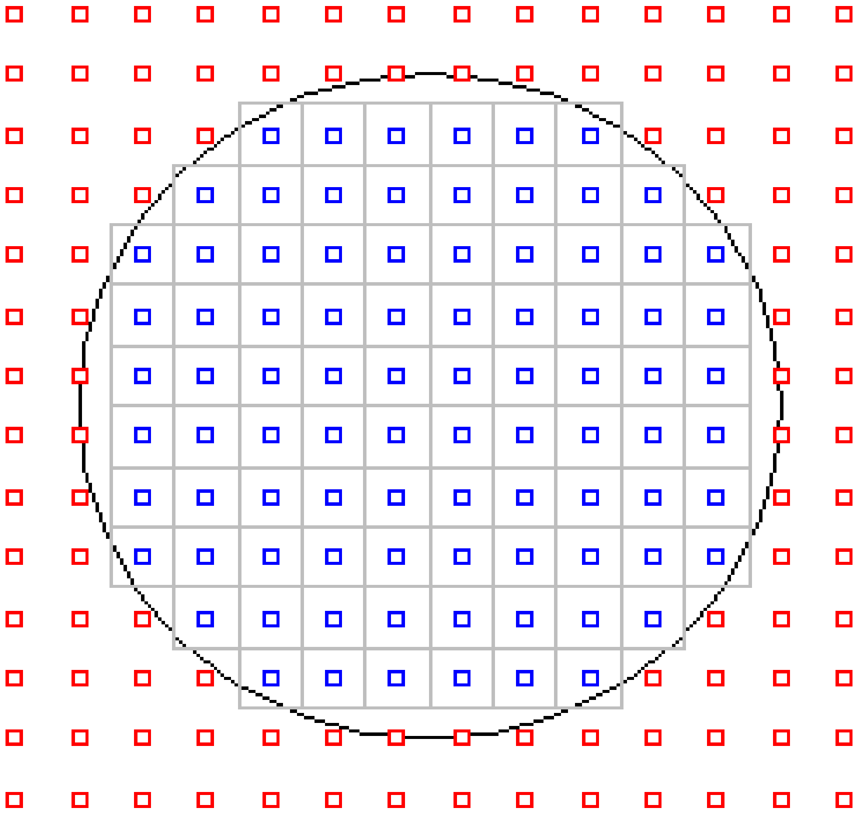
- NURBS volumes:

$$Q_{k,l,o} = V(\bar{u}_k, \bar{v}_l, \bar{w}_o) = \sum_{i=0}^{n} \sum_{j=0}^{m} \sum_{h=0}^{f} N_{i,p}(\bar{u}_k)\, N_{j,q}(\bar{v}_l) N_{h,r}(\bar{w}_o) P_{i,j,k}$$

  - Grid points $\{Q_{k,l,o}\}$, with $k = 0, \dots, n;\ l = 0, \dots, m;\ o = 0, \dots, f$
  - Degrees p, q, r for the parametrical coordinates U, V, W
  - Control points $\{P_{i,j,h}\}$
  - B-Spline basis functions $N_i^p(\bar{u}_k), N_j^q(\bar{v}_l), N_h^r(\bar{w}_o)$
  - Sets of parametric points $\{\bar{u}_k\}, \{\bar{v}_l\}, \{\bar{w}_o\}$

2. Geometry Modelling

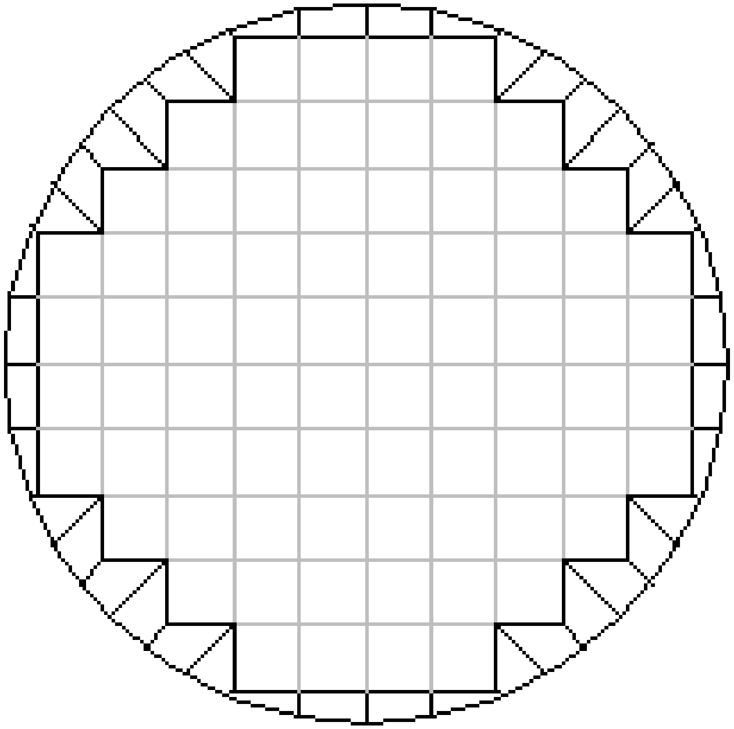
- Efficient and simple meshing algorithms



1. Grid points distribution
2. Inner and outer points classification
3. Parallelepiped hexahedra are generated

2. Geometry Modelling

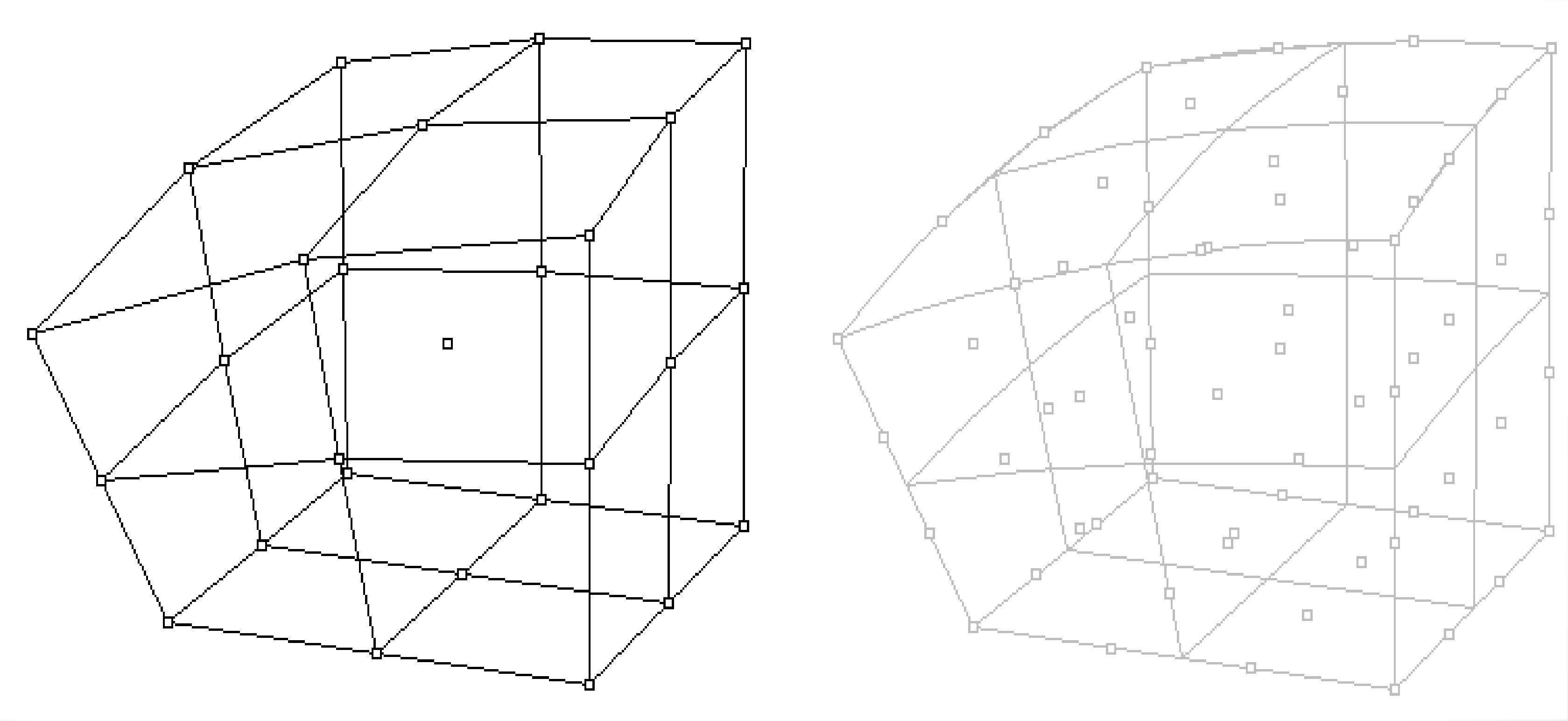
- Efficient and simple meshing algorithms



1. Only inner hexahedra are considered
2. Body-fitted hexahedra are generated in the external layer

2. Geometry Modelling

- NURBS hexahedra provide high accuracy with low density meshes

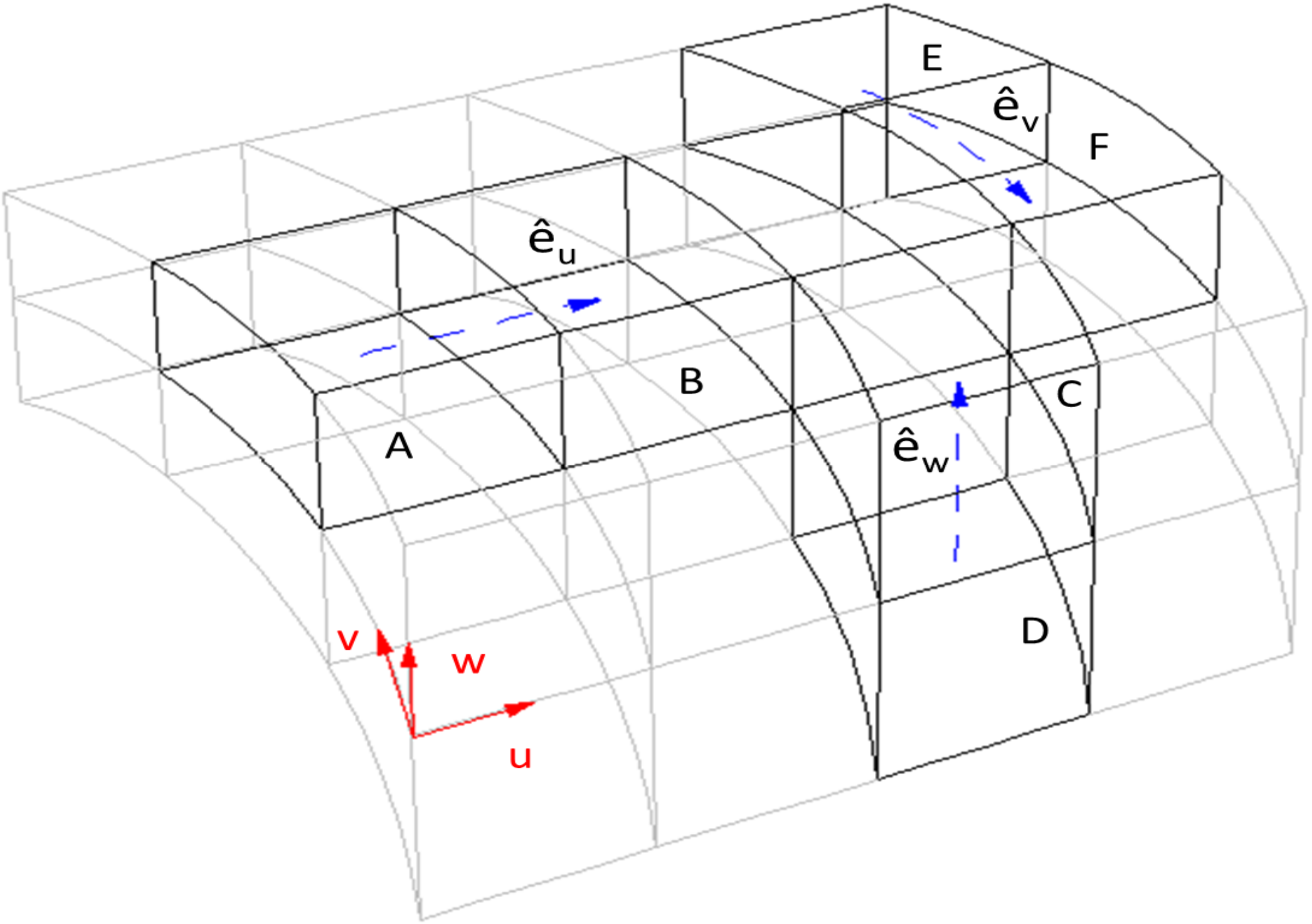


Hexahedron mesh element – Resulting NURBS interpolated volume

3. Method of Moments

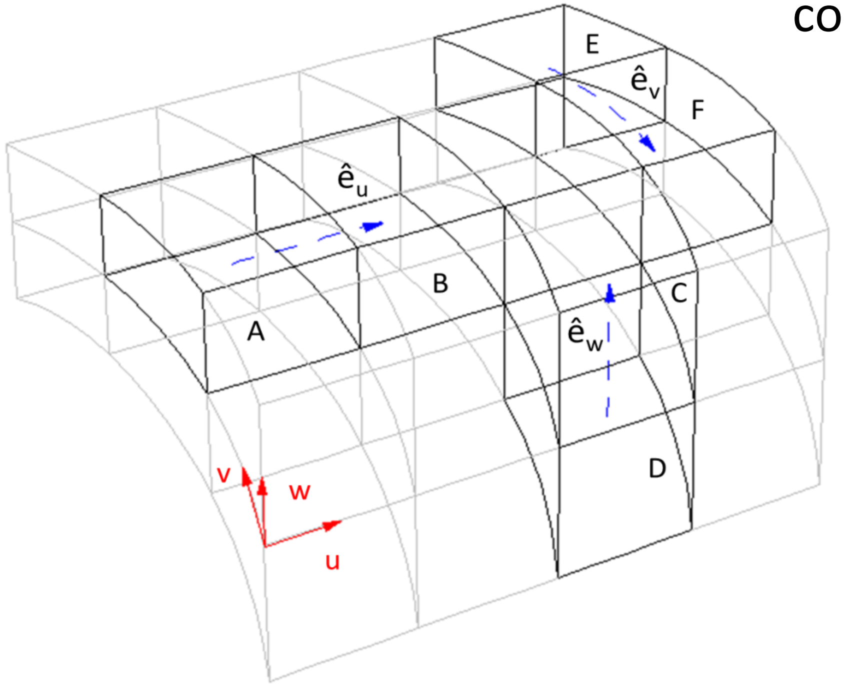
- Volumetric Electrical Field Equation (VEFIE) is applied to NURBS volumes
- Multilevel Fast Multipole Algorithm (MLFMA) to reduce the memory and CPU-time calculation
- Message Passing Interface (MPI) to multithread machines
- Characteristic Basis Function Method (CBFM) with high-level basis functions (CBFs)

3. Method of Moments


E
$\hat{e}_v$
F
$\hat{e}_u$
B
C
A
$\hat{e}_w$
D
v
w
u

Basis and testing functions totally conformed to volumetric dielectric bodies

3. MoM approach I



When applying MoM approach on a dielectric, the coupling terms are computed using:

Inductive term:

$$Z_{ij}^{ind} = \int_{r_a}^{r_b} \left[\frac{j\omega\mu_0}{4\pi} \int_{V_j^C} G(\mathbf{r},\mathbf{r}')\mathbf{J}_j^C(\mathbf{r}')dV' \right.$$

$$\left. + \frac{j\omega\mu_0}{4\pi} \int_{V_j^D} {}'G(\mathbf{r},\mathbf{r}')\mathbf{J}_j^D(\mathbf{r}')dV' \right] d\mathbf{l}$$

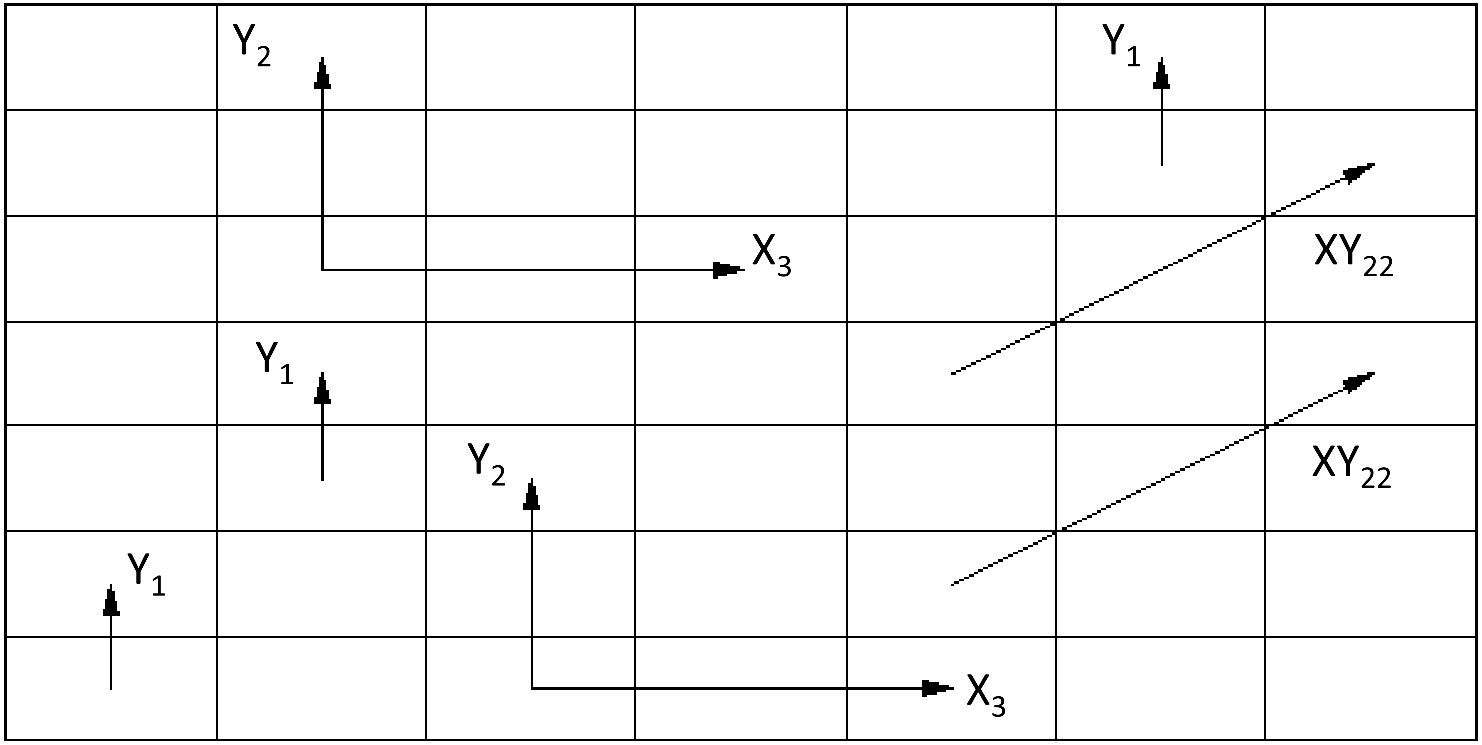
Capacitive term

$$Z_{ij}^{cap} = \int_{r_a}^{r_b} \left[-\frac{1}{j4\pi\omega\varepsilon} \nabla \int_{S_j^C} \frac{G(\mathbf{r},\mathbf{r}')}{S_j^C} dS' \right.$$

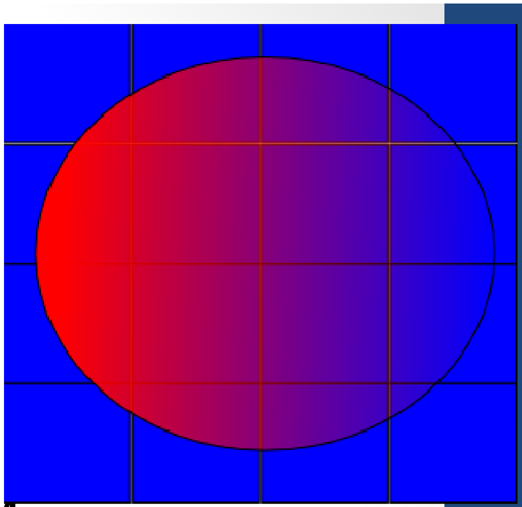
$$\left. + \frac{1}{j4\pi\omega\varepsilon} \nabla \int_{S_j^D} \frac{G(\mathbf{r},\mathbf{r}')}{S_j^D} dS' \right] d\mathbf{l}$$

3. Method of Moments

- Impededance MoM coupling terms are efficiently computed using Toepliz symmetries because of the regular hexahedral distribution


Y_2
Y_1
X_3
XY_{22}
Y_1
Y_2
XY_{22}
Y_1
X_3

3. CBF approach I



Volumetric spaces are computed, and a CBFM block is defined as a set of subdomains of the same material inside of every volumetric space. So, several blocks may belong to the same space, any of them composed by different materials.

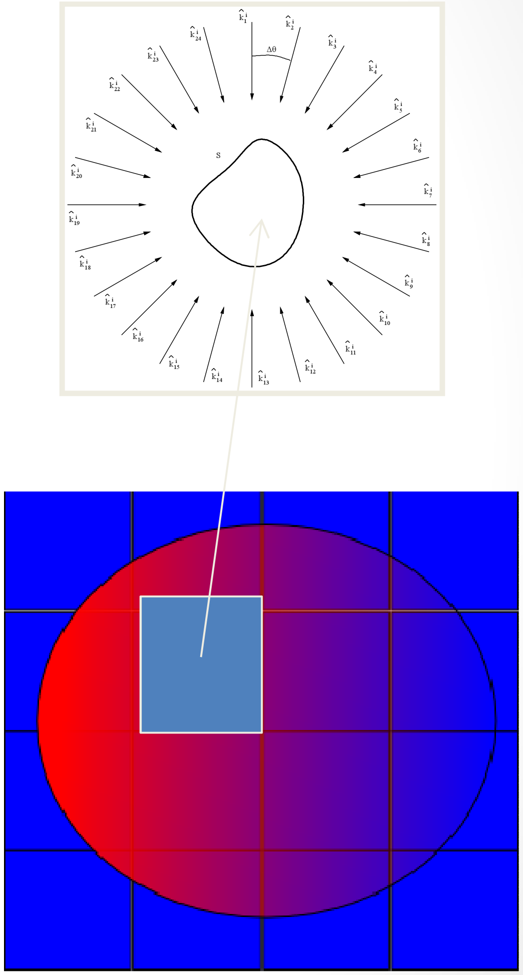
Next, every CBFM block is isolated, and the SVD-derived CBFs are computed.

3. CBF approach I

The generation of CBFs is performed considering a number of plane waves which impinge on the block from different directions.

The currents induced by each of these waves are computed

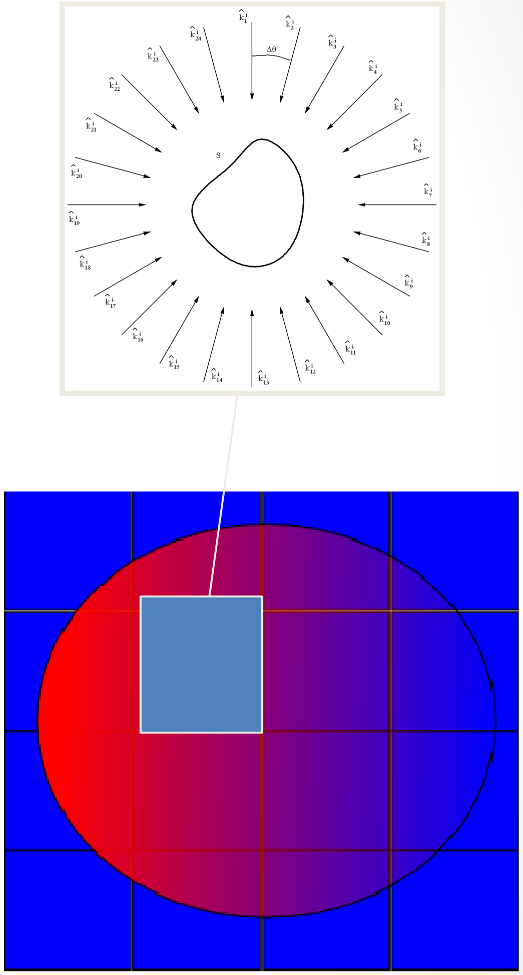
If block contains dielectric elements, MoM is applied to obtain the currents induced by a set of plane waves. It entails solving the following matrix problem in a rigorous way.



$$[Z]^i [J]^i_k = [V]^{inc}_k , \quad k = 1,\ldots,P$$

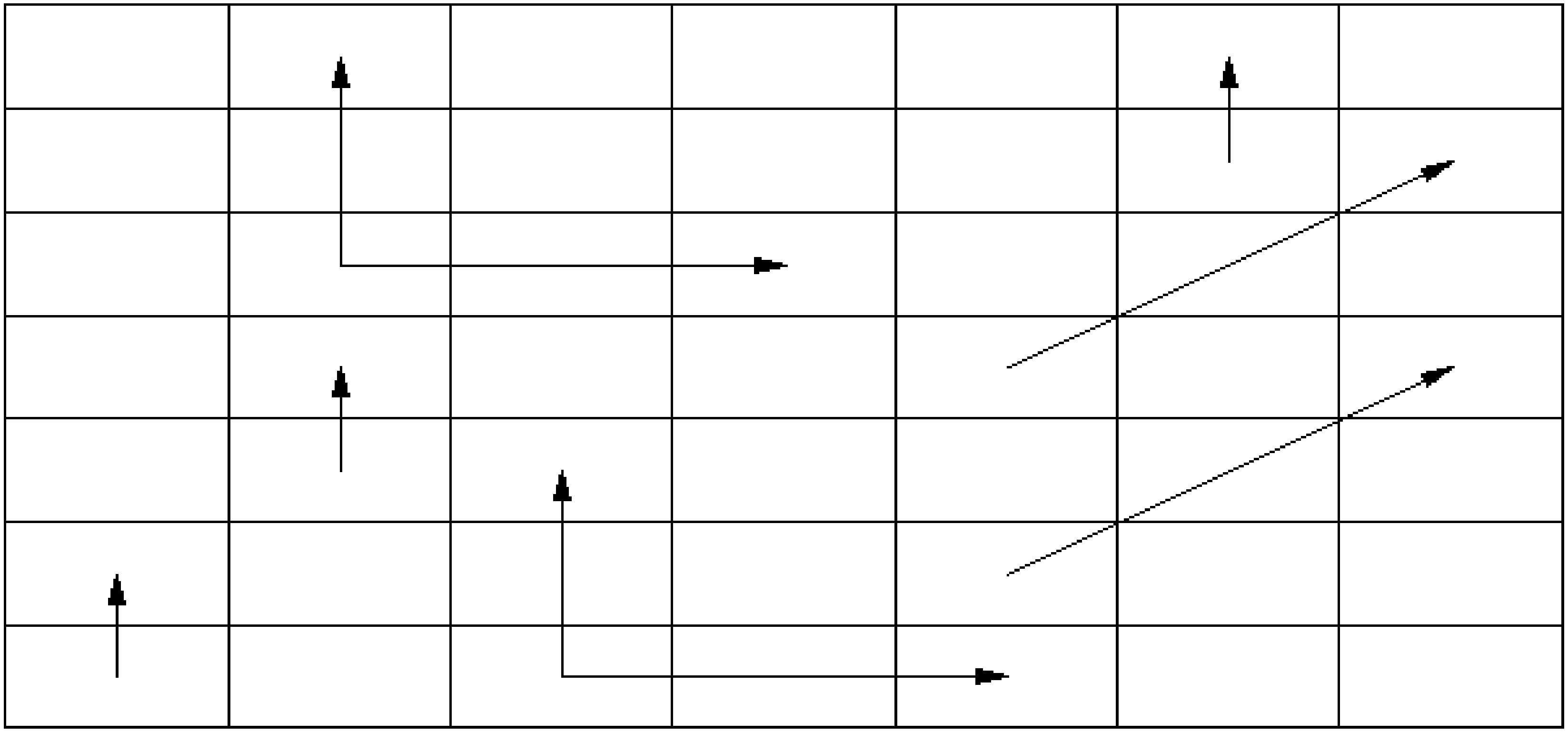
CBF approach II

If block contains perfect conductor elements, MoM or PO-approach can be applied to obtain the currents induced by a set of plane waves, depending on the smoothness of the geometry.


$\hat{k}_1^i$
$\hat{k}_2^i$
$\hat{k}_3^i$
$\hat{k}_4^i$
$\hat{k}_5^i$
$\hat{k}_6^i$
$\hat{k}_7^i$
$\hat{k}_8^i$
$\hat{k}_9^i$
$\hat{k}_{10}^i$
$\hat{k}_{11}^i$
$\hat{k}_{12}^i$
$\hat{k}_{13}^i$
$\hat{k}_{14}^i$
$\hat{k}_{15}^i$
$\hat{k}_{16}^i$
$\hat{k}_{17}^i$
$\hat{k}_{18}^i$
$\hat{k}_{19}^i$
$\hat{k}_{20}^i$
$\hat{k}_{21}^i$
$\hat{k}_{22}^i$
$\hat{k}_{23}^i$
$\hat{k}_{24}^i$
$\Delta\theta$
S

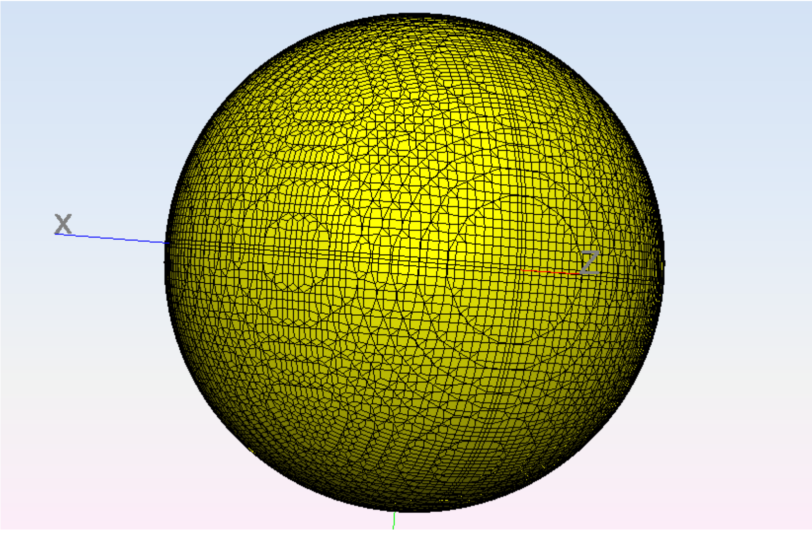
3. CBF approach I

Terms are computed efficiently applying Toeplitz theorem, because of the regular distribution of the elements.

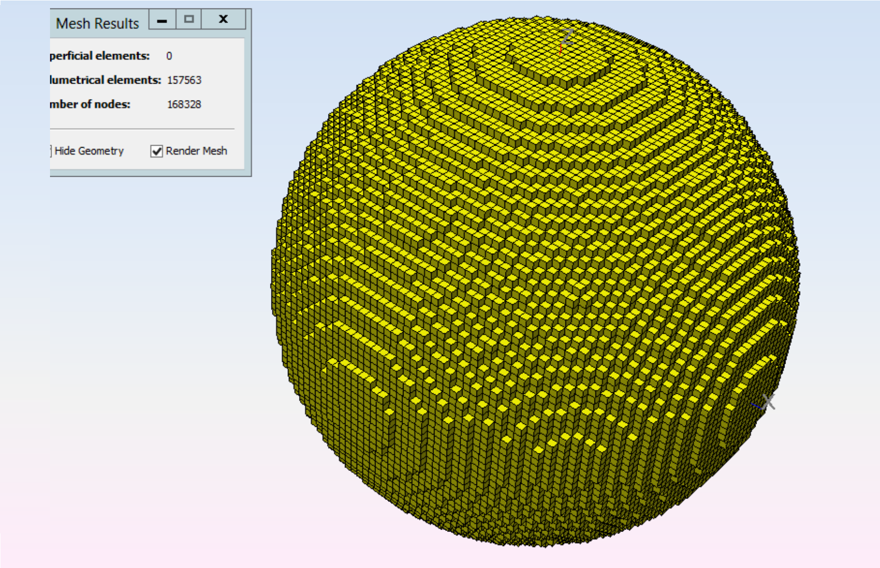


4. Results (Sphere case)

- Dielectric Sphere, radius 1, relative epsilon=4.0, f=1 GHz,
- 10 div per wavelength



Conformed volumetric mesh,
157,163 volumetric elements

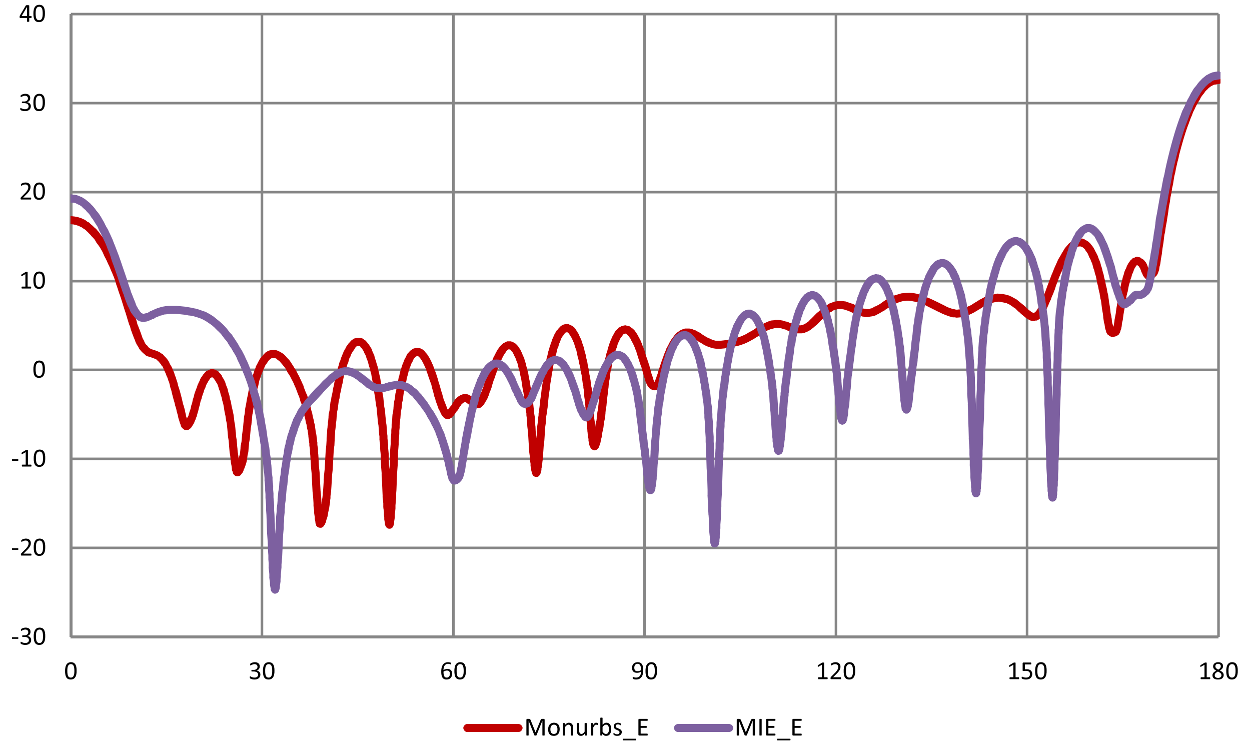


perficial elements: 0
lumetrical elements: 157563
mber of nodes: 168328

Hide Geometry ☑ Render Mesh

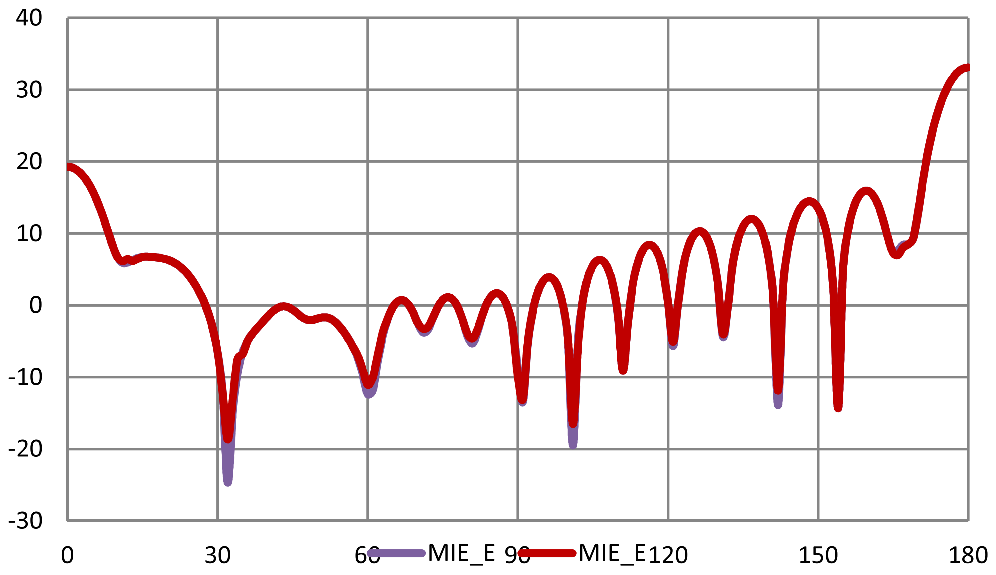
Structured volumetric mesh,
157,563 volumetric elements

4. Results (Sphere case)



Comparison between this approach (Monurbs) and Mie Series, plane E for the structured mesh.

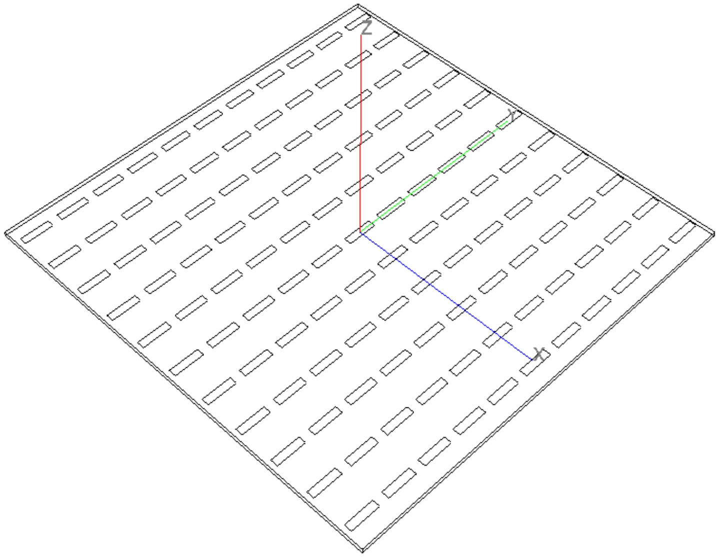
4. Results (Sphere case)



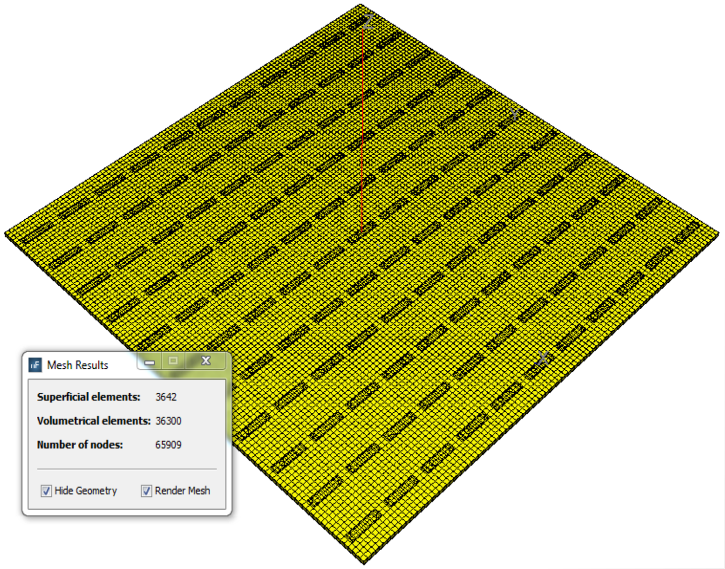
- Comparison between this approach (Monurbs) and Mie Series, plane E for the structured mesh.

4. Results

- Frequency Selective Surface
  - Metallic dipole of 1.875 x 7.5 mm.
  - Replicated in a grid of 11 x 11 with a period of 10 x 10 mm.
  - Dielectric box with dielectric constant ε=4.0 and thickness of 1 mm.



Geometrical model of the FSS



Superficial elements: 3642

Volumetrical elements: 36300

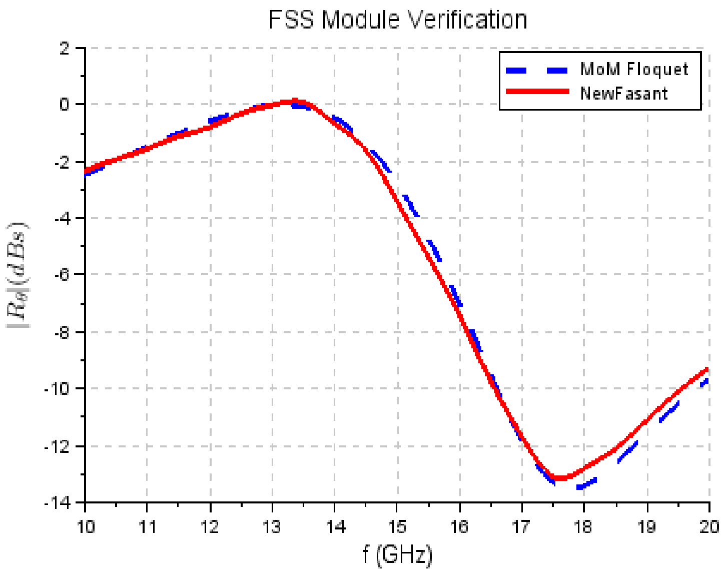
Number of nodes: 65909

☑ Hide Geometry ☑ Render Mesh

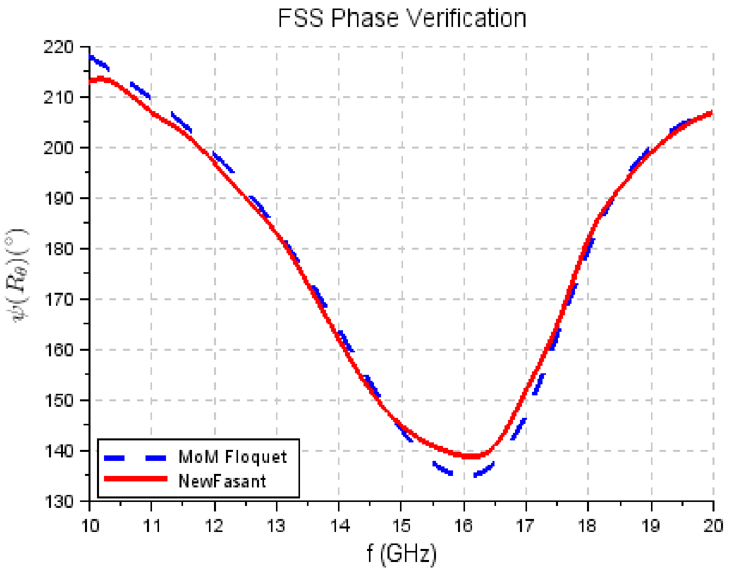
Mesh of the FSS with superficial metallic and dielectric volumetric elements

4. Results

- Frequency Selective Surface
  - Metallic dipole of 1.875 x 7.5 mm.
  - Replicated in a grid of 11 x 11 with a period of 10 x 10 mm.
  - Dielectric box with dielectric constant ε=4.0 and thickness of 1 mm.

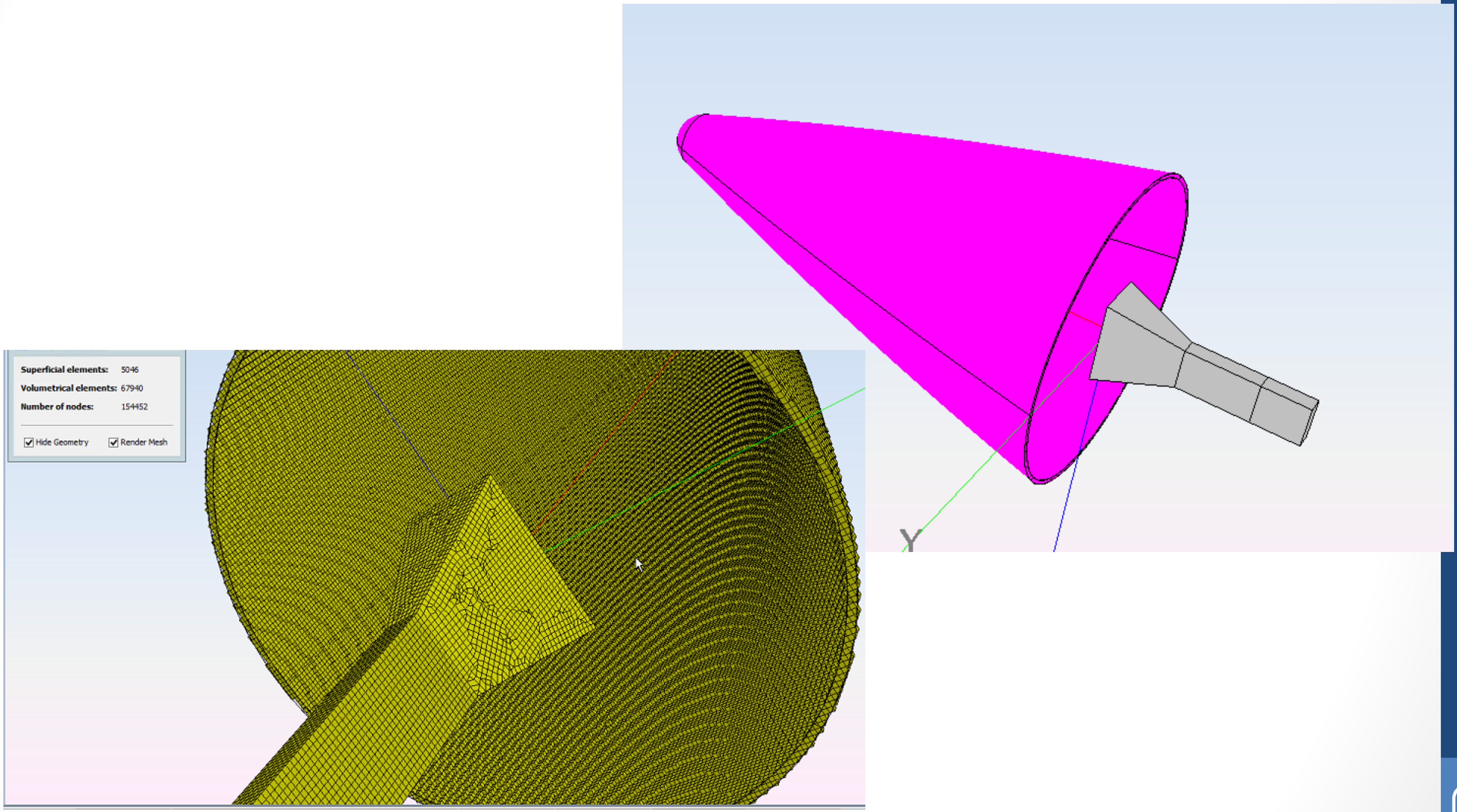


Module of the reflection coefficient at the FSS



Phase of the reflection coefficient at the FSS

4. Results (horn with radome)



Superficial elements: 5046

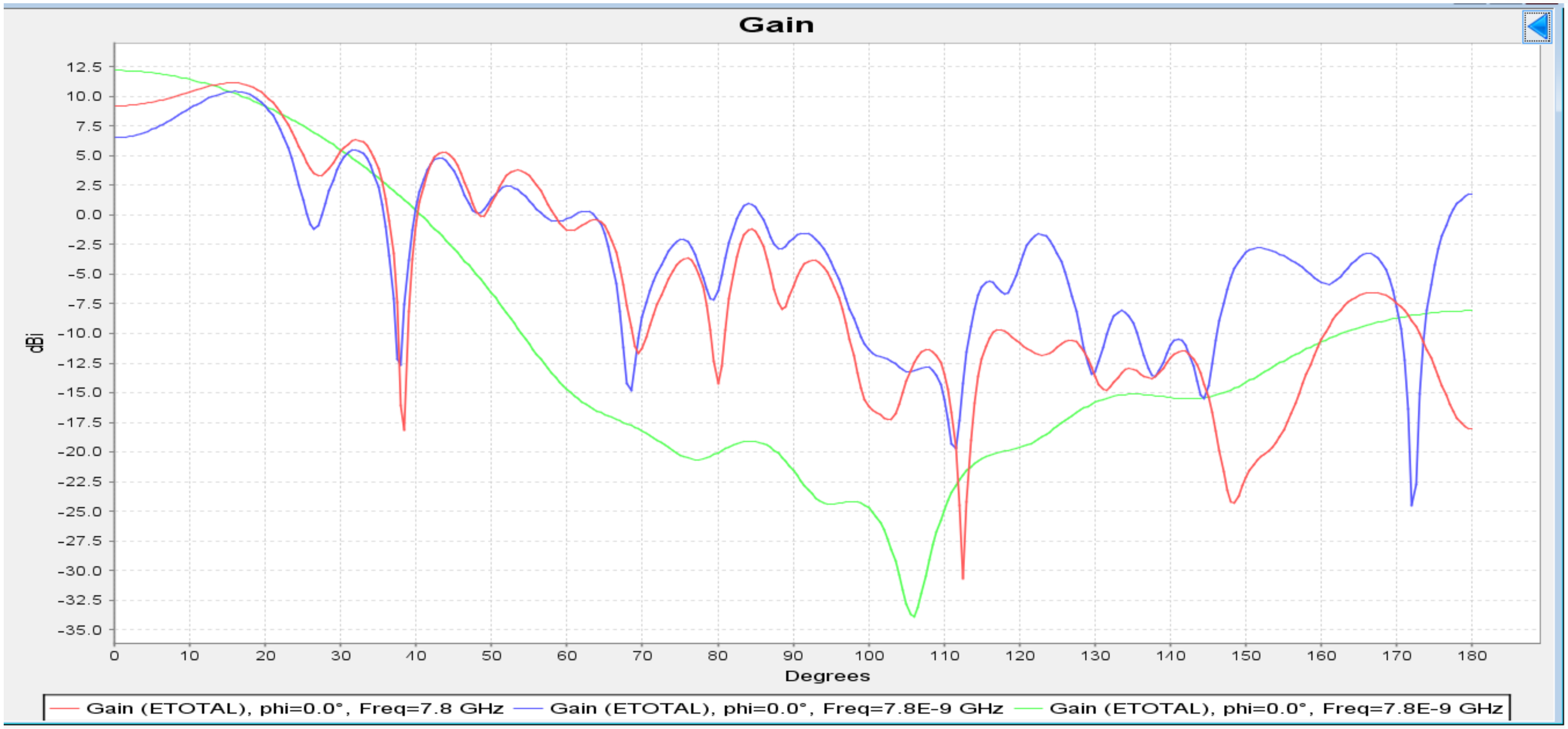
Volumetrical elements: 67940

Number of nodes: 154452

☑ Hide Geometry ☑ Render Mesh

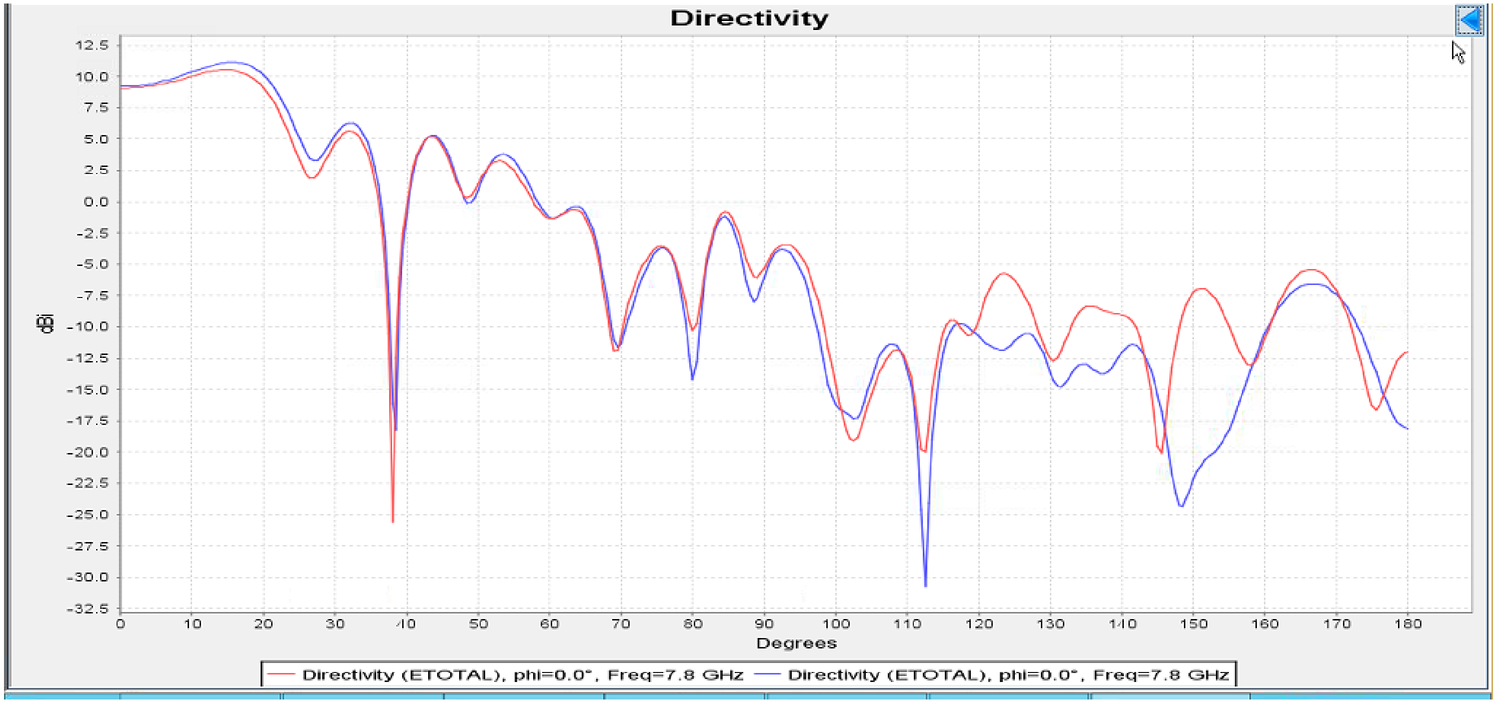
A horn working at 7.8 GHz is covered by a dielectric radome with relative epsilon 4.5-j0.015

4. Results (horn with radome)



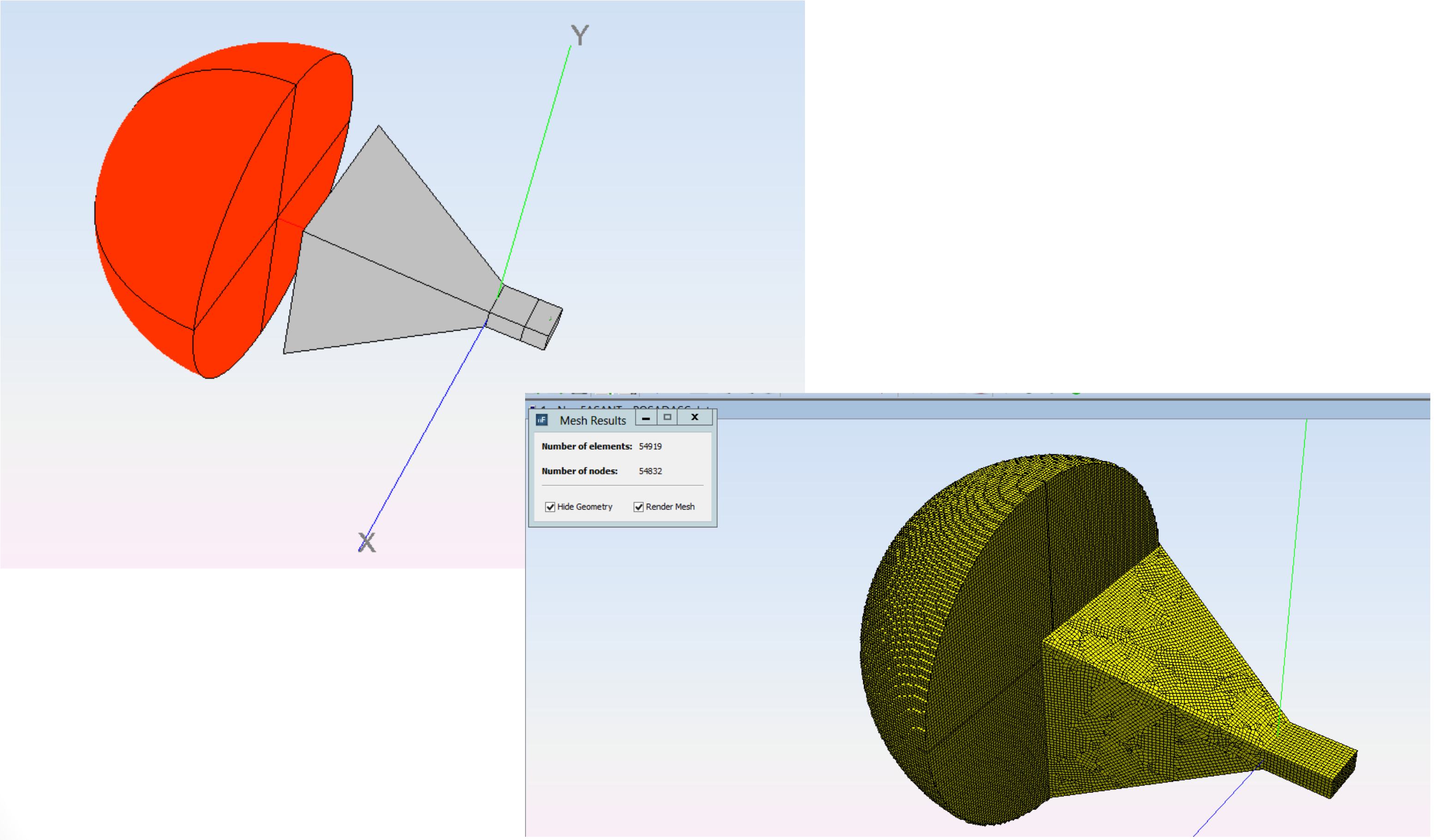
Comparison between present approach (blue), MoM thin layer approach (red) and horn without radome (green)

4. Results (horn with radome)



Comparison between results obtained with a meshing density of 10 (blue) and 20(red) divs/wavelength

4. Results (lens antenna)



Mesh Results

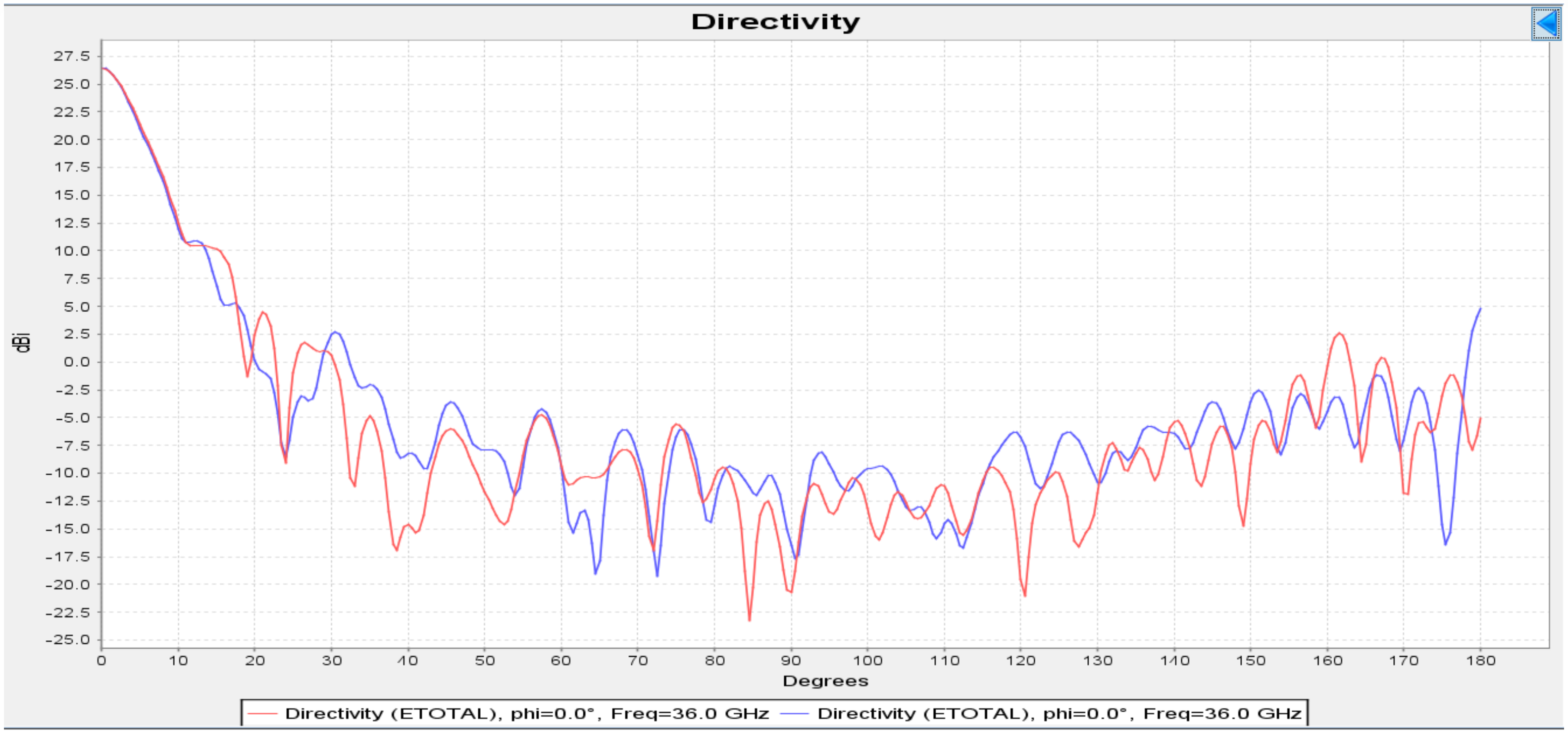
Number of elements: 54919

Number of nodes: 54832

☑ Hide Geometry ☑ Render Mesh

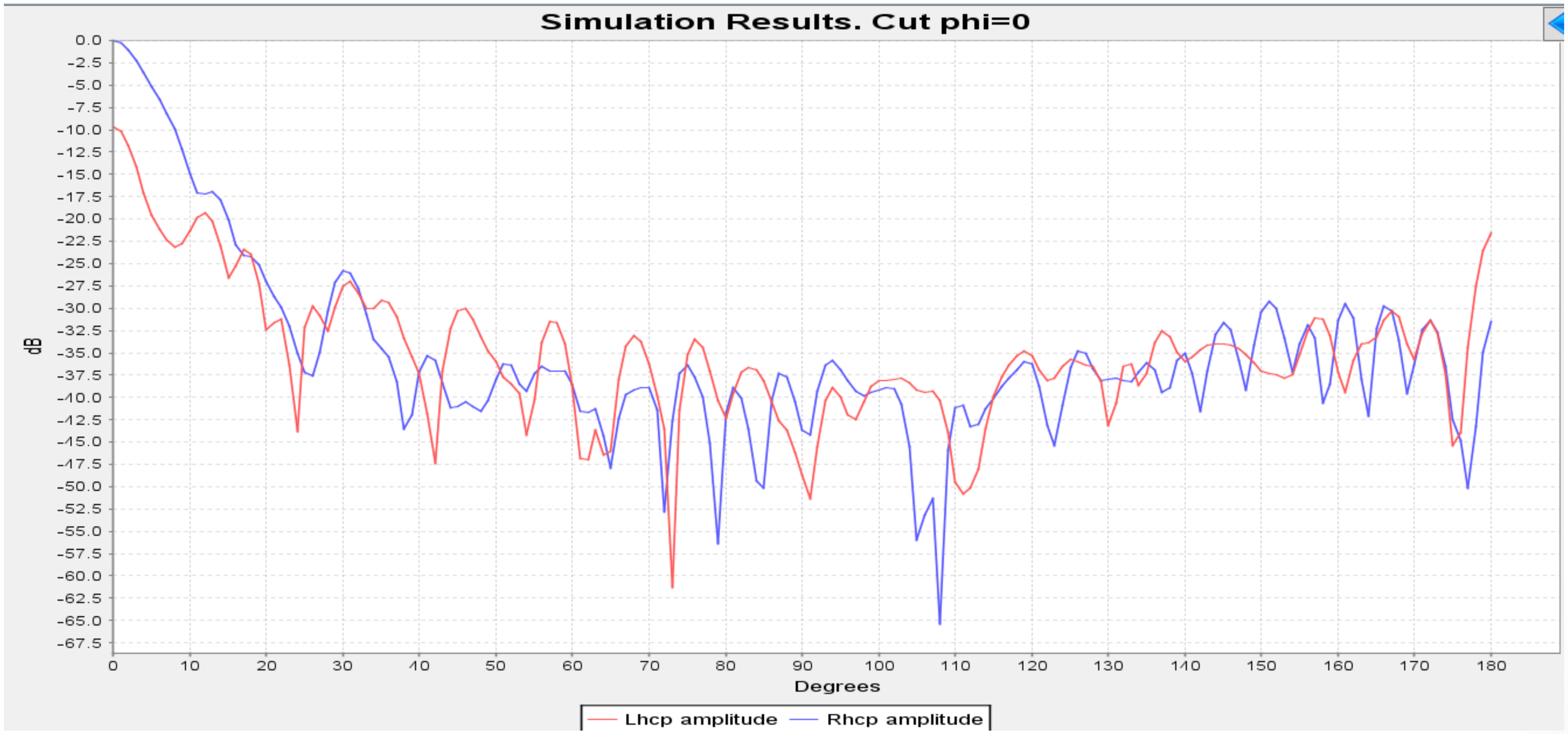
Horn with dielectric lens (Teflon) working at 36 GHz

4. Results (lens antenna)



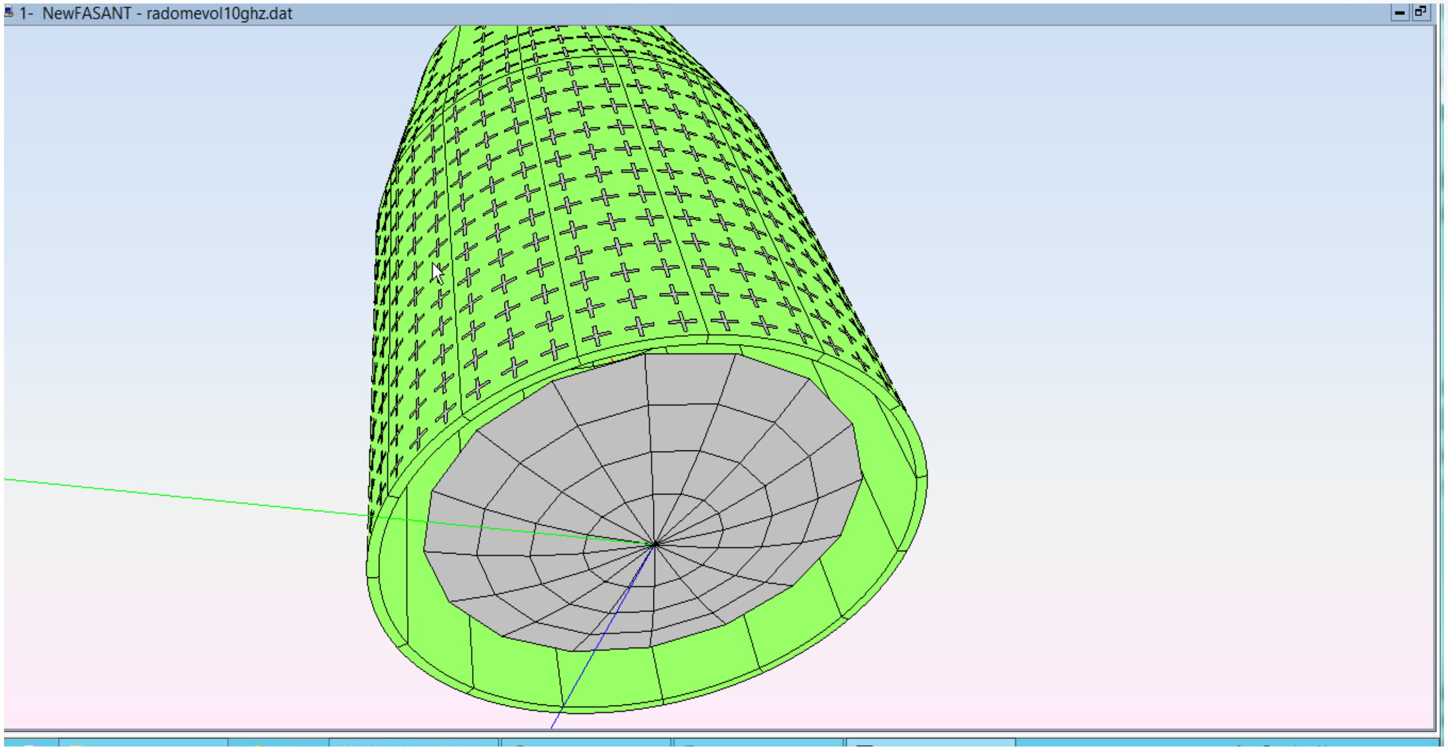
Comparison between results obtained with a meshing density of 10 (blue) and 20(red) divs/wavelength

4. Results (lens antenna)



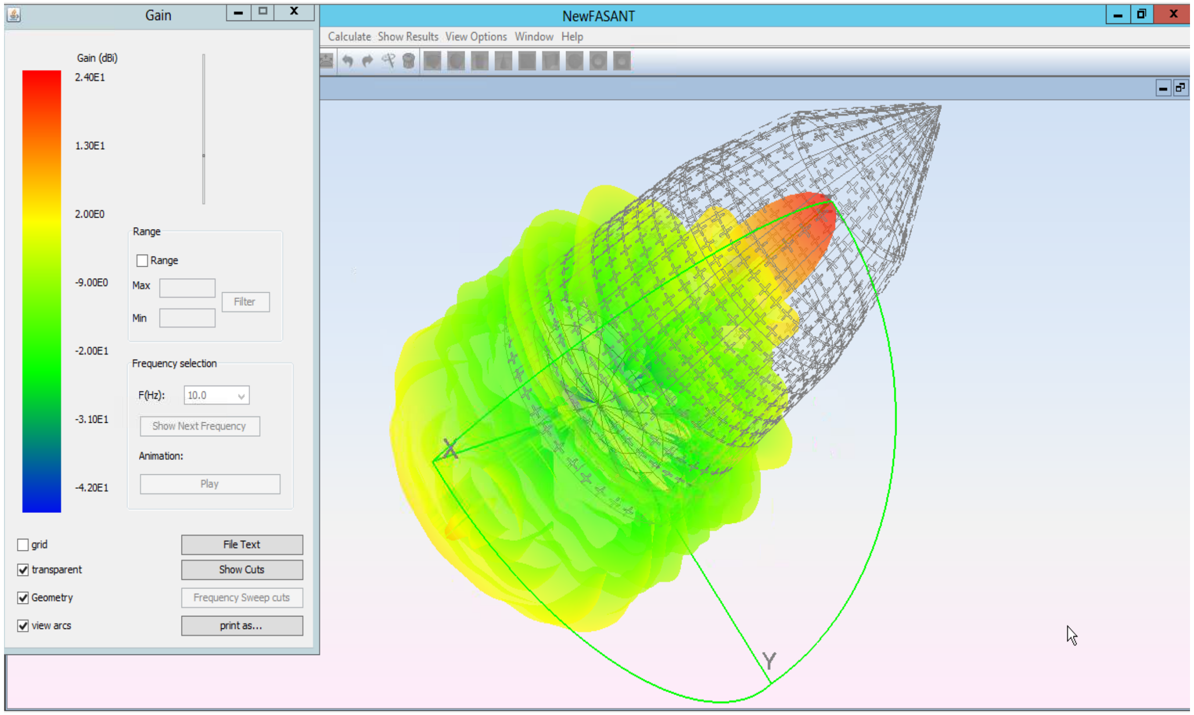
Comparison between co-polar and cross-polar circular polarizarion

4. Results (radome with FSS)


1- NewFASANT - radomevol10ghz.dat

The radome geometry is composed by a single layer structure with a thickness of 5 mm, relative epsilon=1.1, with 24 cm on its basis, a high of 40 cm and fed by a 20 cm reflector antenna with a FSS as shown (f=10 GHz)

4. Results (radome with FSS)


Gain
Gain (dBi)
2.40E1
1.30E1
2.00E0
-9.00E0
-2.00E1
-3.10E1
-4.20E1
Range
Max
Min
Filter
Frequency selection
Show Next Frequency
Animation:
Play
File Text
Show Cuts
Frequency Sweep cuts
print as...
NewFASANT
Calculate
Show Results
View Options
Window
Help
X
Y

☐ Range

F(Hz): 10.0

☐ grid

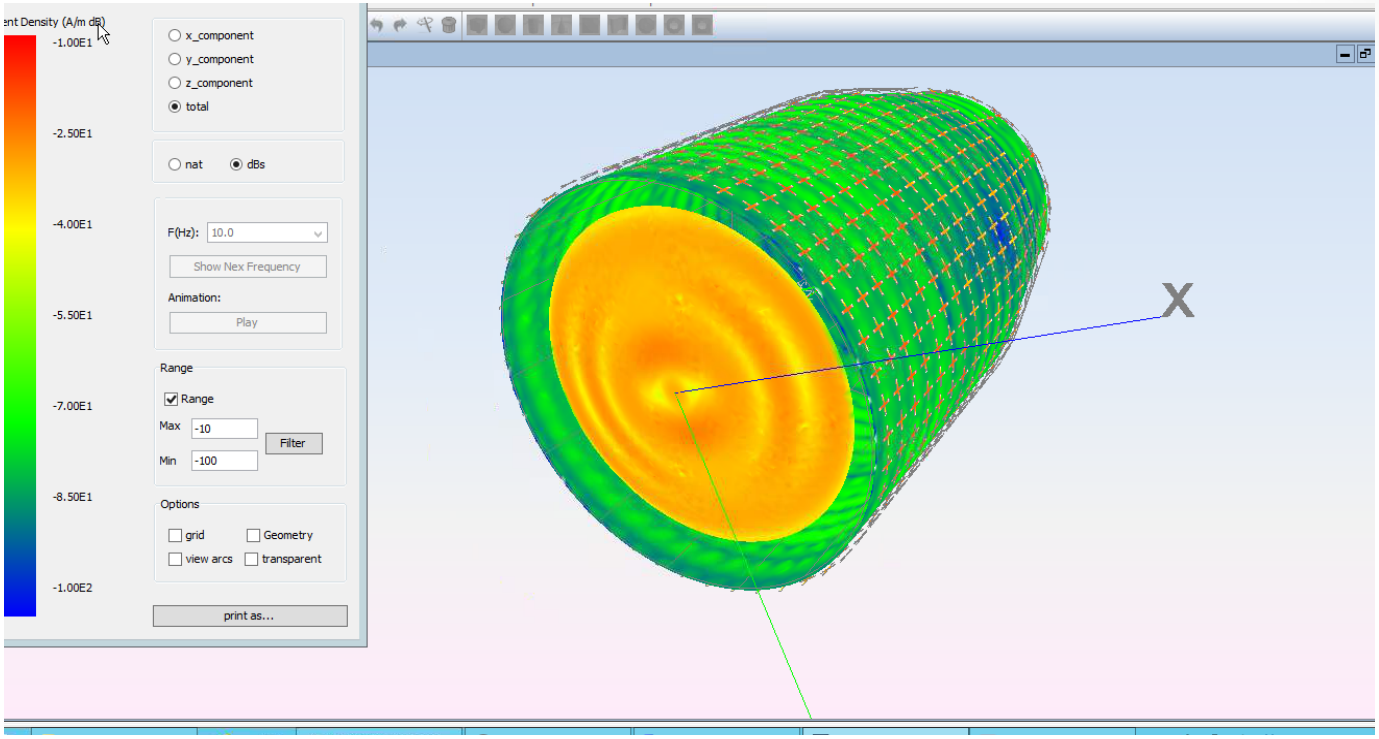
☑ transparent

☑ Geometry

☑ view arcs

3D radiation pattern using the MoM and Thin-Layer (TL) approach

4. Results (radome with FSS)


ent Density (A/m dB)
-1.00E1
-2.50E1
-4.00E1
-5.50E1
-7.00E1
-8.50E1
-1.00E2
Show Nex Frequency
Play
Filter
print as...
X

○ x_component
○ y_component
○ z_component
● total

○ nat ● dBs

F(Hz): 10.0

Animation:

Range

☑ Range

Max -10

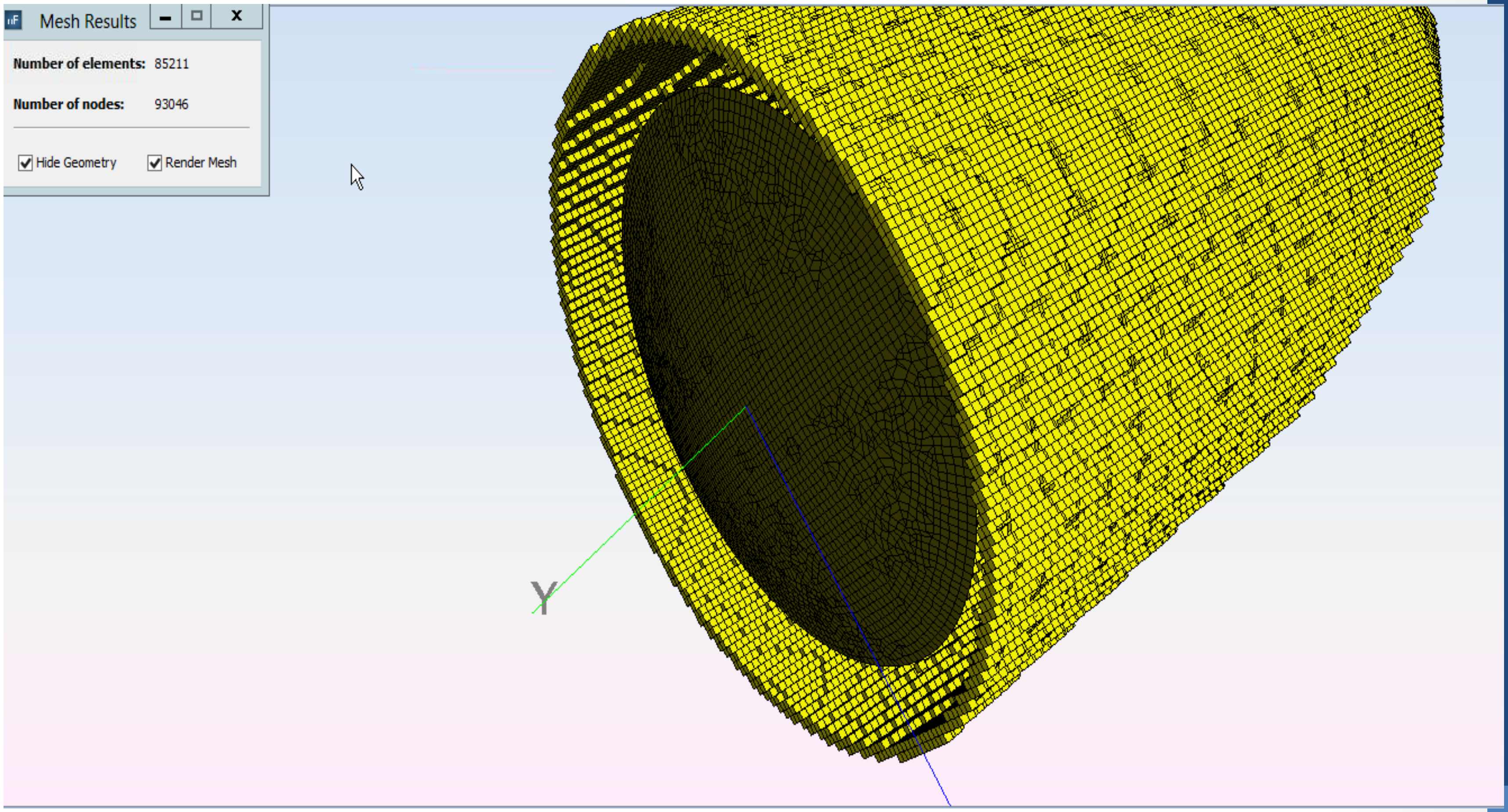
Min -100

Options

☐ grid ☐ Geometry
☐ view arcs ☐ transparent

Current distribution on antenna, radome layer and FSS elements using the MoM-TL approach

4. Results (radome with FSS)



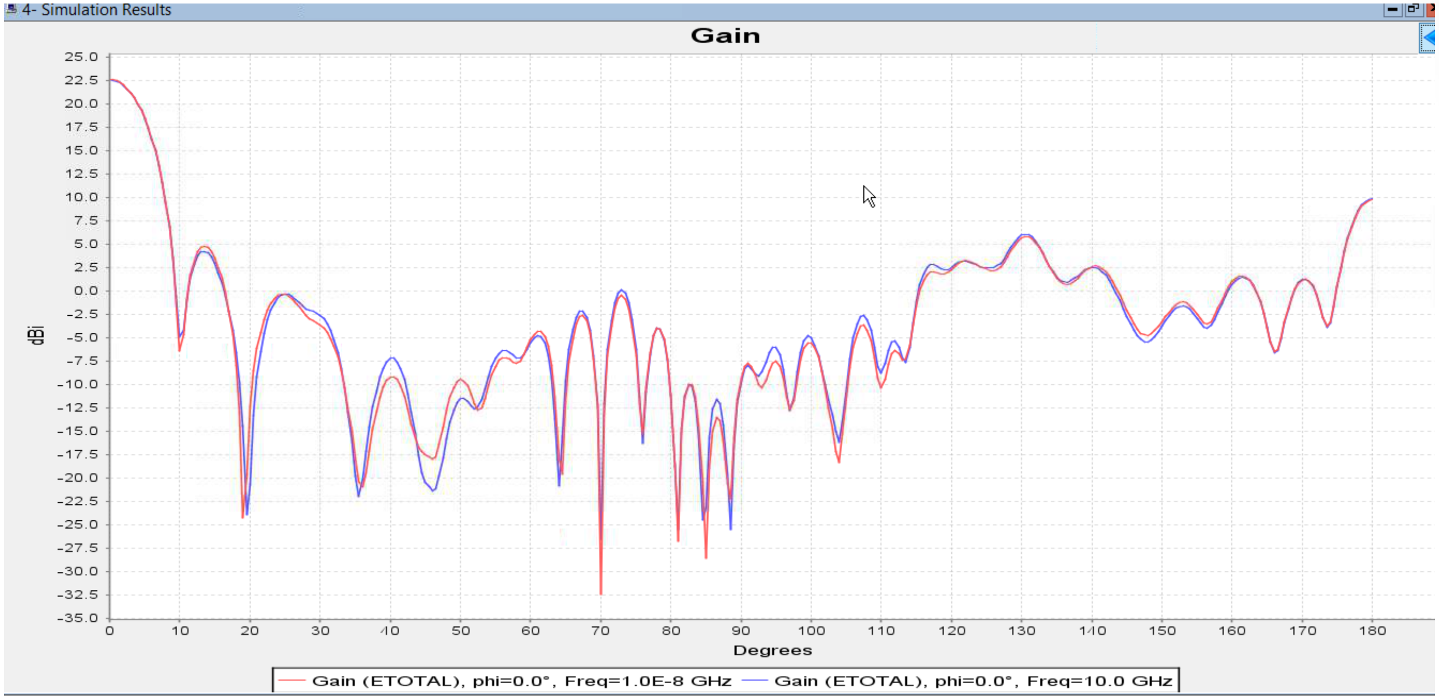
Number of elements: 85211

Number of nodes: 93046

☑ Hide Geometry ☑ Render Mesh

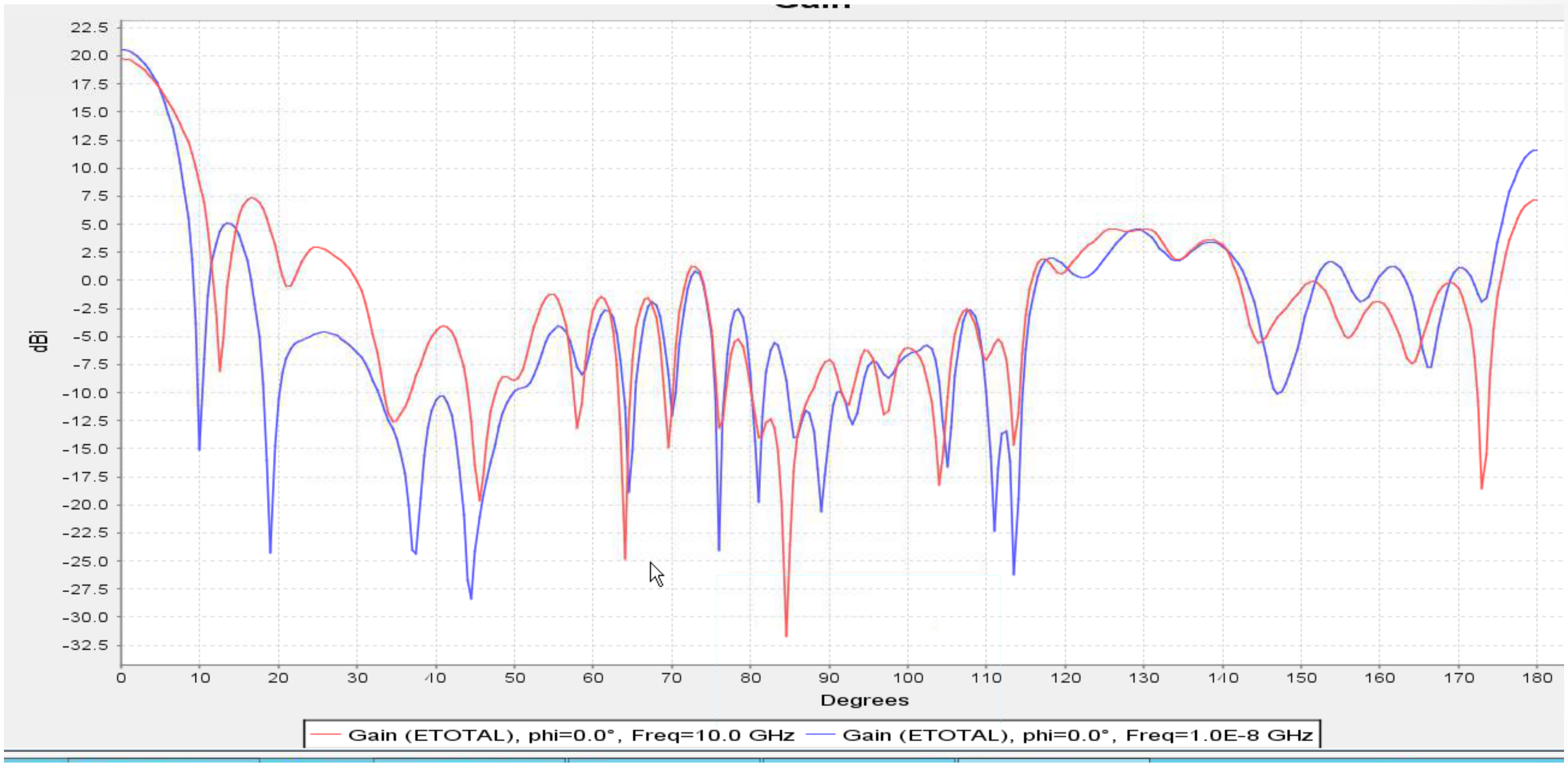
Details of the meshing of the conformed FSS and the dielectric layer using the MoM-VOL approach

4. Results (radome with FSS)



Comparison between MoM-TL and the MoM-VOL radiation pattern cut for phi=0 and 1.1 relative epsilon.

4. Results (radome with FSS)



Comparison between MoM-TL and the MoM-VOL radiation pattern cut for phi=0 and 2.4 relative epsilon

5. Conclusions

- Efficiency of simple meshing techniques
- Accuracy of NURBS entities
- Development of VEFIE formulation of MoM for NURBS volumes
- Speeding up of the MoM on hexahedral distributions using Toepliz symmetries.
- Accuracy of MoM-VEFIE with MLFMA and CBF

Thank you